TEMPERATURE INVERSIONS AT SAN DIEGO, AS DEDUCED FROM AEROGRAPHICAL OBSERVATIONS BY AIRPLANE

By DEAN BLAKE

[Weather Bureau Office, San Diego, Calif., May, 1928]

With the development of apparatus for the exploration of the atmosphere, some of the older conceptions of temperature and wind conditions in the upper air have been altered or greatly modified. It will be recalled that the theory of a constant temperature decrease in the region of the upper air now known as the stratosphere, has been materially changed since Teisserenc de Bort in 1898 carried on his epochal soundings. Wind velocities and directions also have been found to depart materially from the expected, and in the realm of meteorology there is no field more fertile for investigation than that of the upper air.

Since observations were begun by means of airplanes and pilot balloons in San Diego and vicinity, unlooked for temperature and wind variations have been found. Early in the history of aviation, pilots were at a loss to explain the causes of the remarkable temperature inversions encountered aloft, and as the number of pilot balloon soundings increased the existence of unexpected and inexplicable air currents was discovered.

Besides the desirability of improving forecasts for aviation, and widening the scope of our knowledge of aerology, other reasons have prompted the preparation of this paper.

In the first place there has been a specific request for the information it contains. Airplane maneuvers at the naval air station last summer met with such high temperatures at elevations bordering the 1,600 meter level that this year it has been proposed that they be held at a level where the air-cooled motors would not overheat. Again, temperature and humidity are vital factors in the handling of dirigible balloons, and accurate data are necessary. Especially is this true in the vicinity of San Diego, as the Navy Department has begun detailed ground observations in the county for the selection of the most suitable site for the establishment of a base for lighter-than-air craft.

TOPOGRAPHY AND CLIMATE OF SAN DIEGO COUNTY

San Diego County lies at the extreme southern end of California with Lower California adjoining on the south. To the west the Pacific Coast stretches from the northern to the southern boundary. Except for a narrow strip along the coast, it is rough and mountainous with isolated valleys and mesas of limited extent. The mountains, however, are only moderately high, few peaks rising over 6,000 feet, and their eastern slopes abruptly drop into the desert beyond.

Climatically, the littoral strip is mild and equable with a light rainfall that is confined to the winter season. Its infrequent high temperatures are the product of dynamically heated air currents, and therefore are accompanied by low humidities. The most dominant characteristic is the night and morning strata of "high fog," which persists from May to October with remarkable regularity, and is to be found less frequently during the rest of the year. As this protecting veil extends but a few miles inland, the mountains, mesas, and valleys are much warmer in summer and cooler in winter, with large daily ranges in temperatures most of the year and increasing amounts of precipitation with elevation. Beyond, the great interior valleys have typical desert climates; that is, extremely high temperatures in summer and moderate in winter, and little or no rain at any time.

AEROGRAPHICAL FLIGHTS AT NAVAL AIR STATION

Observations of temperature, humidity, and pressure in the upper air have been made by airplane at the naval air station on North Island, San Diego Bay, since January 1923. An aero-meteorograph of the Friez type is in use. To keep the data comparable each flight is made along the same general route over San Diego and its environs, and elevation is made slowly so that the elements will have time to become properly adjusted to the changing conditions. The climb is maintained until the temperature decrease becomes regular or the inversion ceases, which is usually between 2,100 and 2,500 meters.

Until January, 1928, the aerograph was carried by the observer in the cockpit of the airplane. At present it is exposed between the upper and lower right wings, and fastened between the two outer struts in such a manner that the vibration is no greater than before the change. In order that an intimation of the variations between the two exposures might be obtained, the writer on May 2 made a flight with the two aerographs used at the air station. These particular records showed a slight time lag in both the hygrograph and the thermograph by the instrument in the cockpit, and a noticeable tendency not to register the extremes. Undoubtedly, the wing exposure, which is away from heat from the engines, is much the best.

All records used in this paper have been made available through the kindness of the commanding officer of the naval air station, Capt. F. R. McCrary; the aerological officer, Lieut. W. K. Berner; and the chief aerographer, A. A. Stotts and the personnel of his office, who have done everything possible to assist in its preparation. The writer wishes to express his appreciation of the many courtesies extended, and the opportunities presented for obtaining first-hand information.

It is unfortunate that a more continuous record could not have been made. There are many reasons why regular observations have not been practicable, the chief being the lack of available airplanes, unfavorable flying conditions, and the closing of the station on Sundays and holidays. To April 1, 1928, 250 aerographical flights were made. Their distribution by years, months, forenoons, and afternoons is shown in Table 1. At present the record is being taken in a regular and systematic

TABLE 1.—*Distribution of aerographic flights*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
1923—a. m.	3	----	----	1	----	----	----	----	----	5	2	----	11
p. m.	----	----	----	1	----	----	----	----	----	----	----	----	1
1924—a. m.	3	----	1	----	15	6	1	----	----	----	----	----	26
p. m.	----	----	----	----	----	4	19	19	17	13	11	11	94
1925—a. m.	----	----	----	----	----	----	----	----	----	2	1	----	3
p. m.	----	----	----	----	----	----	----	----	----	----	----	----	0
1926—a. m.	----	9	5	5	2	7	4	4	----	----	5	4	45
p. m.	----	3	----	----	6	1	----	----	----	----	----	1	11
1927—a. m.	5	2	6	1	----	2	----	----	----	----	----	----	16
p. m.	1	1	----	----	----	2	----	----	----	----	----	----	4
1928—a. m.	8	16	8	----	----	----	----	----	----	----	----	----	32
p. m.	2	1	4	----	----	----	----	----	----	----	----	----	7
Total:													
a. m.	19	27	20	7	17	15	5	4	0	7	8	4	133
p. m.	3	5	4	1	6	7	19	19	17	13	11	12	117

way at 10 a. m., but in the earlier flights no set hour was consistently used. Efforts are made to obtain pilot balloon soundings at or near the time of the aerological "hops," as they are known on the island, so that synchronous wind velocity and direction data are available.

In the summarization of the data, the temperature gradients found aloft have been divided into three classes; those with a regular decrease with increase in elevation, marked inversions, and slight inversions. For convenience of classification, a continuous rise in temperature of more than 5° C. (9° F.) has been arbitrarily designated a marked inversion, and when below this range, a slight inversion. The distribution of the three groups by months is given in Table 2.

TABLE 2.—*Distribution of flights showing marked inversions, slight inversions, and regular decreasing temperatures*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
Marked inversions	1	1	2	1	11	19	22	19	14	5	3	1	99
Slight inversions	8	8	7	4	7	2	2	4	3	10	7	5	67
Decreasing temperatures	13	23	15	3	5	1	0	0	0	5	9	10	84
Total	22	32	24	8	23	22	24	23	17	20	19	16	250

Owing to their paucity and lack of continuity, no attempt has been made to segregate the date into forenoon and afternoon readings.

It is at once apparent from the table that the temperature inversions encountered aloft are slight during the winter months and well-marked during the summer months. In fact, every observation from June 1 to October 1, save one, showed an increase at some of the levels.

CAUSES OF WINTER INVERSIONS

The inversions during the colder months are readily explained by (1) the presence of clear skies and still air causing a net loss of surface heat by radiation; (2) the importation of hot, dry air above the surface layers; (3) the occasional overspreading of the land areas by a stratum of relatively warm, moist air drawn in from the ocean.

The first type cited occurs during periods of clear, cold anticyclonic weather when low temperatures prevail at the surface, due to rapid loss of heat by radiation. Under these conditions a slight increase in temperature sometimes is found as high as 500 meters. Inversions from this source give us in southern California a better understanding why the so-called "frostless belts" and many of our flourishing and unprotected citrus groves are located at elevations between 500 and 1,500 feet.

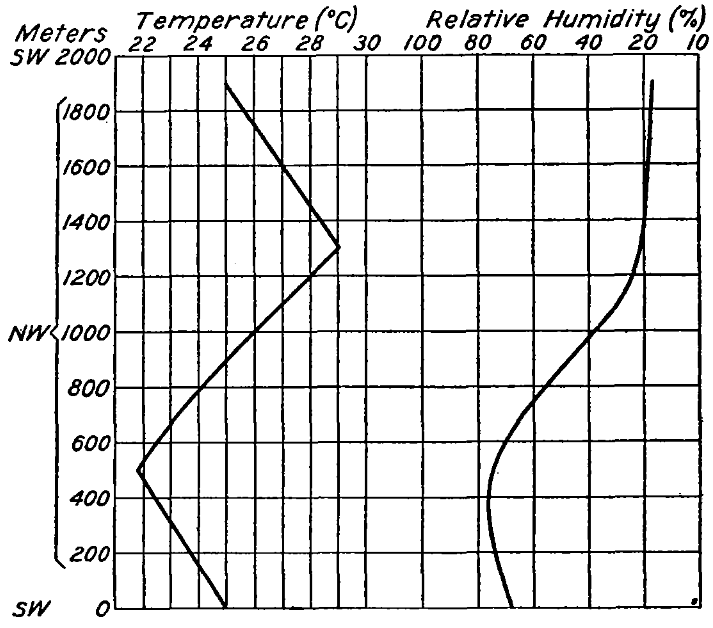
Contrary to expectations, the importation of dynamically heated air appears to be a minor cause of inversions, as it operates only when the warm winds have not reached the surface, which, consequently, is relatively cool. Even then the increases shown are not pronounced, and there is normally little change in temperature to great heights. Air currents of this nature are produced when high pressure overlies the Plateau States, and low barometer is centered over extreme southwestern California or is indicated in the Pacific Ocean off the coast.

Regarding the third type of winter inversions. When the distribution of barometric pressure is such as to cause an indraught of ocean air to overspread the land, a rise in temperature is generally experienced in this layer. For example, the only marked inversion that was recorded in any February occurred on the 25th, in 1927, under these conditions. The aerograph trace sheet on that date showed a steady rise of 7° C. (13° F.), with an accompanying increase in relative humidity of 12 per cent to 500 meters, after which it decreased gradually. Sometimes, however, a decrease is encountered for several hundred meters, which is followed by rising temperature until the top of the strata of ocean air is reached, after which the lapse rate becomes nearly normal.

SUMMER INVERSIONS AND THEIR CAUSES

But a more complex problem is presented by the inversions encountered during the summer flights. Their very regularity is puzzling. The explanation that has been advanced generally has been expressed by Chief Aerographer J. W. Thomas in the following: [1]

At that season (the summer months) the southwestern semipermanent "Low" is at its greatest intensity and it seems to be the concensus of opinion that the inversion is due to the outflow of heated air from the valleys of the interior * * *. The above is a tentative conclusion deduced from observations and subject



to modification. We have found that although the greater number of pilot balloon soundings made in connection with the aerographic flight do show a layer of wind with an easterly component at practically the same elevation as the inversion, nevertheless there are several records showing an inversion while the pilot balloon ascension made at the same time shows a solid west and northwest wind from the surface to an altitude considerably above that attained in the aerographic flight.

In Figure 1, the temperature lapse rate, the humidity curve, and the prevailing wind directions for every 100 meters up to 2,500 meters, derived from 35 afternoon flights during July and August, 1924, are plotted. As anticipated, the lowest temperatures were reached at the average level of the top of the clouds, the decrease for the first 500 meters averaging 0.6° C. per 100 meters, or 0.4° C. less than the adiabatic rate for dry air. From 500 to 1,250 meters a rise of 7.2° C. is shown, and from 1.250 meters on the temperature fall is at the same rate as the initial decrease, or 0.6° C. for each 100 meters. Surface temperatures corresponded generally with those found at 1,800 or 1,900 meters.

[1] Thomas, J. W.: Aerological work at the naval air station at San Diego. Conference on the Physical Oceanography and Marine Meteorology of the Northeast Pacific and the Climate of the Western Part of the United States (p. 23).

Naturally, the relative humidity and temperature curves parallel each other rather closely but in an inverse sense. With a fall in temperature and a consequent decrease in the capacity of the space for water vapor, the relative humidity would increase until the temperature began to rise, when it would decrease.

Although summer averages aloft are comparable to temperatures reported at stations back from the coast at intermediate elevations, little or no daily similarity exists between the two, and, except in cases of widespread warm waves over the district, temperatures in the free air seem independent of surface conditions either in San Diego County or in the great valleys beyond.

It may be of interest to not that the maximum inversion encountered was 16° C. (29° F.) on August 28 1924, and the highest temperature registered at any elevation was 35.6° C. (96° F.) at an approximate height of 1,300 meters.

There is one relation, however, between the free-air and surface temperatures that stands out prominently, i. e., marked inversions are almost certain to be followed by fog or low clouds every month in the year. This relation, though, is not confined to this locality, but has been found to obtain over other parts of the California littoral. Wright in a study of the fog conditions at Mount Tamalpais observed that[2] "* * * the temperature of the upper air must be higher than that of the lower to produce proper conditions for fog formation," and McAdie in Bulletin L writes that[3] "fogs seem to occur at times of steep inverted gradients."

As no figures showing the percentages of winds from the land and sea at the various levels are available, and no discussion of the subject is complete without them, Table 3 was prepared from the 1 p. m. pilot balloon ascensions during June, July, and August, 1924–1927, the same summer periods covered by the aerological data.

TABLE 3.—*Summary of pilot soundings during June, July, and August, 1924–1927 (in meters)*

	Surface	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,000	5,000
N	2	5	10	12	11	1	3	4	3	1	1
NE		6	7	7	13	15	10	13	9	9	7
E		2	6	12	11	10	11	9	6	3	4
SE	3	10	40	42	61	56	55	47	48	27	20
S	17	26	37	33	33	32	27	28	26	7	8
SW	88	85	72	78	82	74	88	80	75	35	25
W	104	39	21	26	27	21	23	21	12	9	3
NW	**130**	**163**	**123**	**95**	46	22	13	14	18	12	12
Calm			2	1	1			1	2		
Total	344	336	318	306	285	231	230	217	199	103	80
Sea, per cent	99	93	80	77	66	65	66	67	67	61	60
Land, per cent	1	7	20	23	34	35	34	33	33	39	40

	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000
N	1			1	1						
NE	4	2	1	1							
E	4	2	2	1							
SE	12	6	2	2	2	2	1	1			
S	5		1								
SW	**19**	7	5	3	4	4	4	3	1	1	1
W	3	2	3	1			1				
NW	6	4	2	1	1	2	1	1			
Total	54	23	16	10	8	8	7	5	1	1	1
Sea, per cent	61	57	69	50	62	75	86	80	100	100	100
Land, per cent	39	43	31	50	38	25	14	20	0	0	0

Even the most cursory examination forces us to draw several obvious conclusions, namely: (*a*) That at virtually every level, winds were from the ocean the larger percentage of the time; (*b*) that between 2,000 and 10,000 meters the percentages from the land and ocean remained fairly constant; (*c*) that beyond 10,000 meters the few soundings obtainable showed an increasing frequency from the ocean; (*d*) that the prevailing direction at all levels was southwest; (*e*) that the northwest currents believed to predominate at the higher elevations, summer as well as winter, were not in evidence.

Although a chart has not been prepared for velocities during the same period, it was further observed that at the soundings under 2,500 meters they were rarely other than light, and when from the eastern or land quarter were more in the nature of a drift than a current.

If we can make our deductions from four year's record, then there must be other causes for the steep inverted gradients besides an overflow of hot air to the coast from convectional action in the Imperial and Colorado Valleys, as inversions occurred at every observation regardless of wind direction.

Hot weather in southern California, in summer as well as in the other seasons, is almost always caused by dynamically heated winds that have their origin in anticyclonic areas over the Plateau States. A relationship between easterly winds at high elevations at Los Angeles and unusually high surface temperatures on the following day has occasionally been noted and referred to in several of the monthly free-air summaries. (See Aerological Observations, Monthly Weather Review, p. 244, May, 1927.) Occasionally, when the pressure gradients are unusually steep, these winds extend to the ocean, but normally the sea breeze modifies the temperature near the coast.

When such pressure conditions prevail, winds are from the eastern quadrant at most levels irrespective of the surface direction. Thus there appears to be a circulation between land and sea which has been confused with the daily land and sea breeze that is so prevalent in many regions. In summer no well-defined interchange has been discovered, but, as Hann expresses it:[4]

> The sea breeze upon the coast of southern California is, however, a wind which partakes rather of the character of the monsoon, because it is an effect of the prevailingly higher temperature in the interior of California as compared with the ocean.

Hann's contention is further proved by the fact that all mountain stations show prevailing winds from the west during the warmer months of the year.

It is highly probable that air movement from the east is given impetus at times by currents originating in the desert regions, but the generally accepted idea that convection is the cause of winds, from that direction is not tenable.

Littoral California enjoys its remarkably cool summer climate because of its proximity to the ocean. As the inland regions become heated an indraught of cool, moist air sets in which is maintained all summer. Considerable cloudiness results that further screens the land from the sun, and it does this so well that the mean temperatures are lower than any in the entire State, except those reported from the highest elevations. A distance of only a few miles from the shore line makes a great difference, and we find monthly averages between 10 and 20 degrees higher at stations a dozen or so miles inland.

There are reasons for believing that this stratum is wedge shaped, deepest over the ocean and thinning out over the land. Optical haze, due to sharply defined temperature layers, and the observations of aviators seem to justify such a conclusion.

Unquestionably, then, the explanation of the inversion lies in the presence of an abnormally cold stratum at and

[2] Wright, Herbert H. Fog in Relation to Wind Direction on Mount Tamalpais, Calif., Monthly Weather Review, vol. 44, pp. 342–344.
[3] McAdie, Alexander G., Climatology of California, Bull. L., pp. 241.

[4] Hann, J. Handbook of Climatology, translated by R. De C. Ward, pp. 156–157.

immediately above the surface extending to about 800 meters, and not in an anomalous air current aloft. Wyatt and Lawing have stated that inversions were not encountered in the few aerological trips they made over the ocean and the Imperial Valley.[5] This is in accordance with my conclusions; they should be found only over the narrow strip paralleling the coast.

CONCLUSIONS

Temperatures aloft in other than the summer months normally decrease with elevation, or, occasionally, there is a small inversion from one of three causes—radiation and conduction in the layers just above the ground; importation of warm, dry air; or an indraft of relatively warm, moist air from the ocean.

Inversions during the summer are of regular occurrence, usually following a drop in temperature from the surface to 500 meters. The highest temperatures occur near the 1,250-meter level, where they average about 4° C. higher than at the surface, and temperatures comparable to those at the surface are reached at 1,800 or 1,900 meters.

That the summer inversions are not caused by an overflow from ascending air currents in the desert valleys to the east is evident. Prevailing wind directions at all heights are from the ocean. Occasionally a drift from the east is observed when temperatures in the interior are unusually high, but as these high temperatures are caused by anticyclones over the Plateau States, then the winds from this direction are also the result of this same pressure distribution.

As already stated there is a stratum of relatively cool air of oceanic origin over the littoral districts. This stratum is overtopped by warmer air of continental origin that slowly drifts oceanward in the hot season. These conditions are brought about by the broader relations of marine and continental climates and may be found in their fullest development in the border zone between the two climates.

DISCUSSION

Chairman Lastreto felt the paper was too technical for a layman like himself to discuss, though he confessed to a deep emotion at the ability with which many old theories had been blasted.

Mr. Gordon wondered where the rising hot air goes from Yuma; it goes up and should come down somewhere, but where?

Mr. Blake stated that Sonora storms are caused by a meeting of the sea and land winds over the mountains; but just how far westward the convectional currents out of the Imperial Valley extend is unknown and is a problem that needs study.

Mr. Gordon said there should be currents aloft out of the valley in practically all directions.

Mr. Blake replied that strong convection over the valley had not been experienced by flyers whom he had interviewed. No extreme bumpiness was reported at the elevations where it is usually found.

Mr. Young asked if different directions of wind were found at different times of the day from the various pilot-balloon observations, to which Mr. Blake replied that while he used the 1 p. m. observations, the aerographers at North Island believed that there was little difference during the 24 hours. Nocturnal data, however, were not available and therefore the answer was in doubt.

Major Bowie explained that by means of numerous pilot-balloon reports received in the San Francisco office from stations in the southwestern quarter of the United States it is a simple matter to construct the isobars for various elevations up to 4 or 5 kilometers. Thus the changes in wind direction at various levels, ranging from an inflowing circulation at the surface to an outflowing circulation aloft, indicate that as we strip off the isobaric surfaces over the interior, one by one, the LOW at the surface gradually gives way to a HIGH in the upper air.

At the higher elevations the barometric gradient is actually outward instead of inward. We are in such a case dealing with a theoretical thermal cyclone as described by Ferrell. The explanation of the wind circulation aloft at San Diego is very easy, it seems to me; the air is moving in a wide circle, and while it may originate in the region to the southward of the Imperial Valley it passes seaward in a circuitous route aloft, and when observed at San Diego is moving in a clockwise direction, because at high levels it constitutes the outflow of air from the anticyclone capping the low-pressure area, which exists only in the lowest atmospheric strata.

[5] Lieut. B. H. Wyatt and M. R. Lawing. Discussion of Papers in Bulletin Am. Metl. Society, Nov., 1923. Pp. 154-157.

THE MEASUREMENT OF SKY COLORING

By FRANZ LINKE

[Frankfort on the Main, Germany]

In the year 1922 I approached Prof. W. Ostwald, of Grossbothen, with a request for the making in his laboratory of a technical, well-defined, and certainly reproducible blue scale for the estimation of the color of the sky. With a well-known obliging interest in all applications of his color lore Professor Ostwald undertook the task and put at my disposal a rather large number of copies of a blue scale in seven parts, which showed logarithmic transitions from pure white to ultramarine blue. I then numbered the pure white 0 and the ultramarine 14, so that the even numbers indicated the several color steps of the scale and the odd numbers interpolations. Since that time the scale has been employed at many places for the estimation of the coloring of the sky. Professor Ostwald himself reports on the color-technical principles of this blue scale, so that I have only to make statements on the method and purpose of the observations and the results to date.

Method of observation.—The observer places himself with his back to the sun and observes for at least 30 seconds the bluest point in the sky, which is 70° to 90° distant from the sun in the direction of its meridian. Without removing his eyes from the sky the observer arbitrarily opens the scale at a tone and quickly brings it into the range of the eye so that it comes into the light of the sun. After some practice, even when the exact coloring of the sky does not contain white and blue only, the observer forms an opinion whether the blue tone of the scale is lighter or deeper as compared with the blue of the sky. The scale made up in book form is then turned until the observer either finds a color tone in sufficient agreement with the coloring of the sky or is